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COMPARATIVE FE ANALYSIS OF AUTOMOTIVE LEAF SPRING USING COMPOSITE MATERIALS

SUDHIR KUMAR JAISWAL[1*], DR. S.C. GAJBHIYE[2*], SURINDER KUMAR[3], PANKAJ SIDAR[4]

[1]M. Tech Scholar, Department of Mechanical Engineering,

[2,3,4]Assistant Professor, Department of Mechanical Engineering,

[1,2,4]Vishwavidyalaya Engineering College Ambikapur, Chhattisgarh, India

[3]Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab, India

ABSTRACT

In today's competitive world of the automobile industry, it is found that the continuous emergence of environmental issues, hiking of price in all respect, it is necessary to find the solution and analyse the few parameters such as weight reduction, optimise the design in the automotive component. In this paper, the material comparison have been considered and applied to the geometric model of the leaf spring, which is a very important component of the automobile segment. The geometric model of leaf spring with steel and composite material is established using the three dimensional software and then imported into the higher end finite element software to analyze its strength such as stress, deflection, and stiffness. The weights of two sheet plates have been considered for both steel and composite material and compared the weight reduction. The result showed that the E glass fibre composite leaf spring of two sheet plate has an 80% weight reduction as compared to the traditional steel leaf spring. This comparison showed remarkable the strength effect and the reduction in cost effectiveness can be easily achieved in the production sector.

KEYWORDS: leaf spring, finite element analysis, ansys, composite material, e-glass, s-glass, kevlar fiber, epoxy, multi leaf.

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Original Article

I. INTRODUCTION

The composite materials have the characteristics of excellent mechanical properties, low density, and ease of manufacturing; and hence, they are widely used in aerospace, ship building, automotive and other fields. However, with the increasingly fierce competition in the automotive industry and the importance of environmental protection in various countries, the demand for lightweight design of automobiles is also increasing. Leaf spring (also known as leaf spring) is a traditional and common automotive suspension elastic component. Its mass accounts for about 5% ~ 7% of the vehicle mass. The lightweight design of the leaf spring can not only reduce the weight of the vehicle, but also improve the comfort and stability of the vehicle. At present, domestic, and foreign automakers are working on researching and developing composite leaf springs to replace traditional steel leaf springs (Figure 1). Many relevant studies have been carried out on the lightweight of the car, the comfort of driving and the stability of the handling. Data shows that for every 10% reduction in the weight of traditional fuel vehicles, the fuel consumption can be reduced by 3% to 4%. For every 10% weight loss of an electric vehicle, its cruising range can be increased by 5% ~ 6% [1]. Therefore, realizing automobile lightweight is one of the effective ways to save energy, and it is also the future development trend of the automotive field. Many related studies have been carried out on composite leaf springs abroad, which gives the information about design and structural analysis of

composite leaf spring made of glass fiber reinforced polymer (GFRP). They represent two full length leaves in which one is with eyed ends and five graduated length leaves and material is 65Si7 [2]. The natural frequency of composite leaf spring is higher than that of steel leaf spring and is far enough from the road frequency to avoid the resonance. It is to study that composite materials have more elastic strain energy storage capacity and high strength to weight ratio than steel; therefore, it is concluded that composite leaf spring is an adequate replacement for the existing steel leaf spring in an automobile [3].

The material for the composite leaf spring is E-Glass/Epoxy unidirectional laminates or GFRP. The FE modelling for this has been generated in Pro-E 4.0 and imported in ANSYS-11. Using ANSYS workbench, it was observed that the composite leaf spring has a 19% increase in deflection, within the camber range and a 19% decrease in stiffness, which means that it is less than steel leaf. It is concluded that this absorbs more energy than spring thus providing good comfort raft. Composite leaf springs reduce bending stress by up to 24%, which means less stress with the same load bearing conditions. The finite element optimization results show that the optimal spring width is a hyperbolic decrease, and the thickness increases linearly from the spring lug along the shaft seat. Compared with the steel spring, the optimized composite spring has much lower stress and high natural frequency. The weight of the spring is about 80% lower without rolling ears. Raghavedra et al. describes the design and analysis of composite mono leaf spring [4]. They use an existing mono steel leaf spring for modelling and analysis of a light vehicle. A composite mono leaf spring with Carbon/Epoxy composite materials is modelled and subjected to the same load as a steel spring. The design constraints were stresses and deflections. The composite mono leaf springs have been modelled by considering a Varying cross-section, with a unidirectional fiber orientation angle for each lamina of a laminate. Static analysis of a 3-D model has been performed using ANSYS 12.0. Compared to mono steel leaf spring, the laminated composite mono leaf spring is found lesser stresses. Experimentally investigation has been done using composite mono leaf spring for static loading. The result showed that the stresses induced in Carbon/Epoxy composite leaf spring were nearly 42% less than steel leaf spring. Hence, they finally concluded that composite material could be used efficiently for lightweight vehicles to meet the requirements, along with considerable weight reduction [5, 6, 7].

Figure 1: A Traditional Multi-Leaf Spring Arrangement [8]

Babu et al. analyses leaf spring as made of composite materials, which can reduce the leaf spring weight without reducing load carrying capacity and stiffness. Therefore, this paper aims to present a general study on the performance comparison of composite (E-Glass/Epoxy and Jute E-Glass) leaf spring and conventional leaf spring. In this paper, the

author uses a 3-D modelling software ANSYS V5R20 where Leaf spring is modelled and imported in ANSYS 12.0. The conventional composite leaf springs were analysed under similar conditions using ANSYS software. The stresses and deflection developed in steel leaf spring and composite leaf spring are significant differences. When they compare both leaf springs with the same parameter, they found the deflection is less in composite leaf springs with the same loading condition. Conventional steel leaf spring is also 5.5 times heavier than Jute E-Glass/Epoxy leaf spring. Material saving of 71.4 % is achieved by replacing Jute E-Glass/epoxy in steel for fabricating the leaf spring [8, 9, 10].

Composites have been prepared with different weight fractions of bamboo fibers. XRD and optical microscope have been used for the characterization of composites. It is concluded that the enhancement of tensile strength, flexural strength and hardness of bamboo fiber epoxy composites depends on fiber concentration and fiber-matrix-adhesion [11]. The conventional steel leaf spring and weight reduction ratio is achieved. Static structural tool has been used of ANSYS. A three layer composite leaf spring with full length leave. E-Glass/epoxy composite material has been used. Conventional steel leaf spring results have been compared with the results obtained for composite leaf spring. E glass/epoxy material is better in strength and lighter in weight as contrast with conventional steel leaf spring. A wide amount of study has been conducted in his paper to investigate the design and analysis of leaf spring and leaf spring fatigue life. Results demonstrate that composite leaf spring deflection for a particular load is less compared to conventional leaf spring. Stress generated in the E-Glass/Epoxy leaf spring is lower than steel leaf spring [12, 13, 14].

The specific work of this paper is as follows: the geometric modelling of leaf spring has been prepared for using Solid works 2017 and then FE analysis has been carried out using advanced ANSYS. The constructed FE model with metal has been constructed, in which the various mechanical properties have been incorporated of E-glass fiber, S-glass fiber, Carbon fiber, and Kevlar fiber. The two forms (single leaf spring and double leaf spring) are compared using the finite element model. The composite material leaf spring is compared with the steel plate spring. The difference in weight, stress and deflection has been observed, which comprehensively affects the cost-effectiveness, material performance and manufacturing process. According to the leaf spring stress formula, the single-piece E glass the fiber composite material leaf spring is structurally designed, and the optimized variable width composite leaf spring is compared with the original composite material leaf spring in terms of performance and lightweight effects.

METHODOLOGY

1.1 Designing Procedure for Leaf Spring

The design procedure has been shown as a flow chart in figure 2, in which from the available data, noting the loads to be supported, number of springs required, space available, and other working conditions. Then, choose a suitable material for the leaf spring and assume its design yields stress in bending. Based on the requirement, adopt prestressing method if required. Usually, this prestressing or nipping is preferable to make all the leaves to be equally stressed. Generally, among all the leaves, adopt at least two leaves, including master leaf as full-length leaves, and consider other leaves as graduated leaves. Later, determine the stress induced in the corresponding leaves and determine the deflection produced using proper equations. Similarly, evaluate the width and thickness of leaves. Find out the length of leaves, camber, clipping load, the radius of curvature, etc.

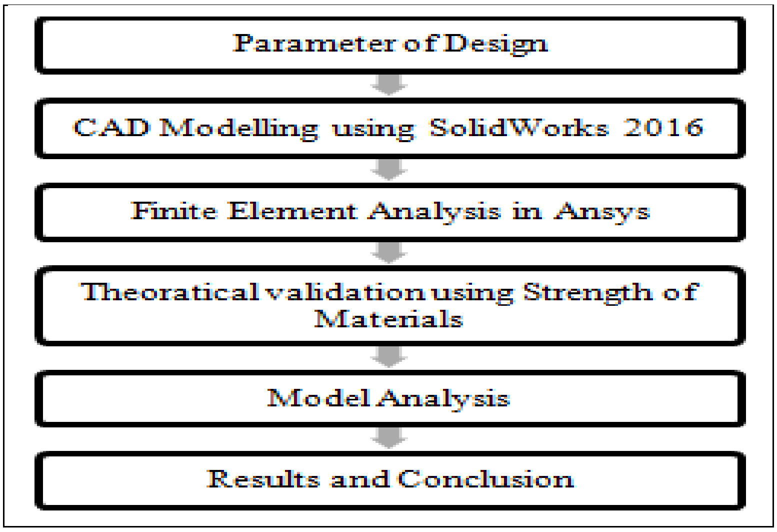

Figure 2: Design Procedure

2.2 Material properties

The raw material used is steel leaf spring 65Si7. Its correlation energy parameters are shown in Table 1. A significant force receiving portion fiber-reinforced composite material is largely taken depending on the fiber properties. The content, lay angle and the state of use considering the material used temperature range, the mechanical properties, the structure of the force to and process factors such as currently used for manufacturing a reinforced composite material leaf spring Material mainly is divided into E glass fiber, S glass fiber, carbon fiber, and Kevlar fiber. Among them, E-glass fiber has the lowest cost among these four reinforcing fibres. The parameters of these four materials are shown in Table 2.

Table 1: Physical Parameters of Leaf Spring Steel Material

SN	Parameter	Numerical Value
1	Elastic Modulus	2.1×10^5 MPa
2	Poisson's ratio	0.266
3	Tensile Strength	550 MPa
4	Yield Strength	250 MPa
5	density	7860 kg / m^3

Table 2: Material Properties of Composites [4]

Parameter / Material	E glass Fiber	S glass Fiber	Carbon Fiber	Kevlar Fiber
E_{11} / MPa	45000	50000	209000	95710
E_{22} / MPa	1,000	8000	9450	104500
G_{12} / MPa	5000	5000	5500	25080
V_{12}	0.3	0.3	0.27	0.34
Density /kg-m^{-3}	2000	2000	1540	1402
Tensile Strength	1100	1700	1677	1600
Compressive strength	675	1000	893	517

II. MATHEMATICAL FORMULATION

3.1 Analysis of Leaf Spring Characteristics

The function of a leaf spring may be analysed through some simple types of beams and their characteristics. Consider a cantilever beam of rectangular cross-section, whose width is 'b' thickness 'h' and length 'L', is subjected to a load 'F' at its free end. Due to this load, the beam tries to bend, and the maximum bending moment at the fixed end is

$$\sigma_{max} = S_b = \frac{M}{Z} = \frac{MY}{I} = \frac{Fl\,h/2}{bh^3/12} = \frac{6Fl}{bh^2}$$

$$\sigma_{max} = \frac{6Fl}{bh^2}$$

Maximum deflection, obtained at the free end is given by,

$$\delta_{max} = \frac{Fl^3}{3EI} = \frac{Fl^3}{3E\,bh^3/12} = \frac{4Fl^3}{Ebh^3} = \frac{2}{3}S_b\frac{l^2}{Eh}$$

$$\delta_{max} = \frac{2}{3}S_b\frac{l^2}{Eh}$$

Were,

E is the Elastic modulus of the spring material.

Since the leaf spring is similar to a simply supported beam, let us consider a simply supported beam of length L (2l) and a central load of W (2F). The width and thickness of plates (or beam) may be 'b' and 'h,' respectively. For this case, maximum bending stress induced at the centre is

$$\sigma_{max} = \frac{MY}{I} = \frac{\frac{WL}{4}\times\frac{h}{2}}{\frac{bh^3}{12}} = \frac{\frac{2F\times2l}{4}\times h/2}{bh^3/12} = \frac{6Fl}{bh^2}$$

$$\sigma_{max} = \frac{6Fl}{bh^2}$$

Similarly, maximum deflation at the centre is

$$\delta_{max} = \frac{Wl^3}{48EI} = \frac{2F\times(2l)^3}{48E\times bh^3/12} = \frac{4Fl^3}{Ebh^3}$$

From the above two analyses, we can conclude that the simply Supported beam of length L(2l) subjected to a load W(2F) may be treated as a Double cantilever beam fitted side by side and loaded at its ends.

3.2 Design of Leaf Spring

Since the leaf spring is constructed by a certain number of full-length Leaves and others by graduated length leaves, it is designed based on combined strength and deflection characteristics of full-length and graduated leaves (Table 3).

Table 3: Main Parameters of Double Leaf Spring

SN	Parameter	Numerical value
1	P_0 (no load)	6800 N
2	P (full load)	16000 N
3	L_1 (main spring)	1350 mm
4	L_2 (the second piece)	1200 mm
5	b (wide)	70 mm
6	h (high)	11 mm
7	H_0 (free arc height of main Spring)	138 mm

Semi elliptical leaf springs are almost universally used for suspension in light and heavy commercial vehicles. In the present work, the leaf spring of heavy-duty commercial vehicles is taken for modelling and analysis to compute and compare results. Leaf springs are made from flat plates in which each leaf is modelled separately, and then this constructive parametric model is assembled in solid works (Figure 3).

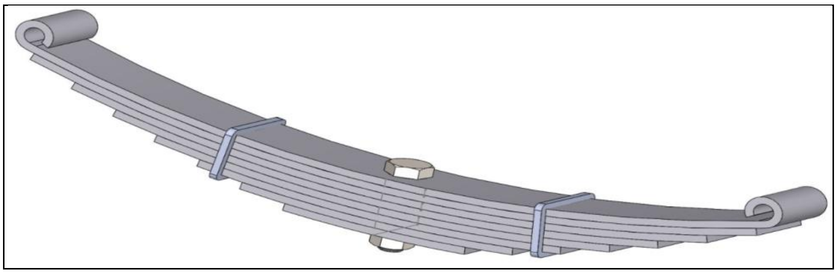

Figure 3: 3D Model of Leaf Spring in Solid Works

3.3 Establishment of finite element model of automobile leaf spring

The object of this research for a light vehicle leaf spring object of interest using a composite material in place of conventional steel leaf springs to reduce the vehicle's weight with improved comfort, safety, and fatigue resistance prolonged use of the leaf spring. There are four general cross-sectional forms: constant width and thickness, variable width, and constant width. Becomes a wider variable thickness to simplify the design and manufacturing herein. Double leaf spring steel sheet cross-sectional study with a constant thickness using the first form and width of dimension generous length of 1350 mm × 70 mm × 11 mm. The main parameters of the leaf spring shown in Table 3 using the original plate spring leaf spring size and form, i.e., two-piece (Master Leaf) as shown in figure 4. In ANSYS three-dimensional model of the two-piece leaf springs analysis for comparing the result with constant width varying thickness of the leaf spring is designed.

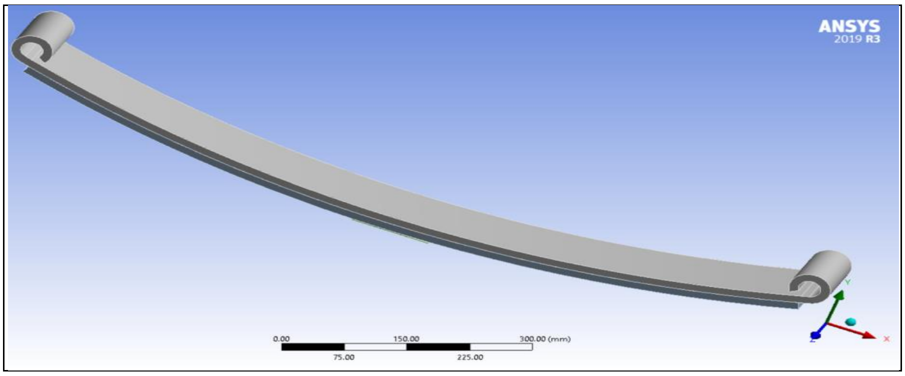

Figure 4: Two-Piece Leaf Spring Model in ANSYS

III. MODEL MESH AND CONTACT

4.1 Model Mesh and contact

Import the three-dimensional model established by SolidWorks 2017 into the finite element analysis software ANSYS 2019 R3. In Ansys Solid 185, solid elements are used for hexahedral for meshing element and mesh size of 5 mm. Solid185 unit having 8 nodes, which can facilitate the establishment of contact pairs, and can also be applied to nonlinear and large deformation analysis because the steel plate has large deformation under load. So the use of surface contact phenomena soft flexible square plate between the reed the contact pair takes the concave surface of the leaf spring as the "target surface". Target surface conducts the simulation, taking the convex surface of the steel plate as the "contact surface". Use contact surface to simulate and appropriately segment the entity then sweeps the mesh dividing unit can improve the mesh quality two the finite element model of various forms of leaf springs is shown in figure 5.

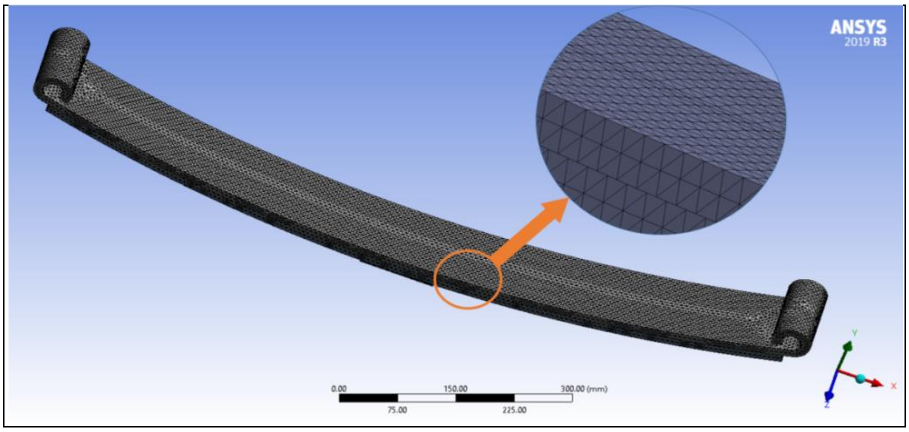

Figure 5: Mesh Model in Ansys

4.2 Defining the Element and Material Properties

The finite element model of the leaf spring under applied load constraints to calculate the equivalent leaf spring seeks and displacement response. The known material properties of four different fiber-reinforced composite materials have been used for the calculation of the four composite leaf springs. In this finite element model, every leaf was modelled with eight-node 3D brick elements, and then five- node 3D contact elements were used to represent contact and sliding between adjacent surfaces of leaves. An average coefficient of friction of 0.03 was taken between surfaces. The axle of the spring was assumed to be fixed, and loading was applied at the eyes corresponding to the length of each half of the spring. A finite element stress analysis was performed under static and total bump loading. Another analytical solution was carried

out using the SAE standard design formulas for leaf springs. Maximum normal stress from finite element analysis was compared to the experimental solution under static and total bump loading and had 23% and 3% errors, respectively. There is a good correlation for maximum deflection from all three methods. The equivalent stress and displacement response of the composite material leaf springs were calculated.

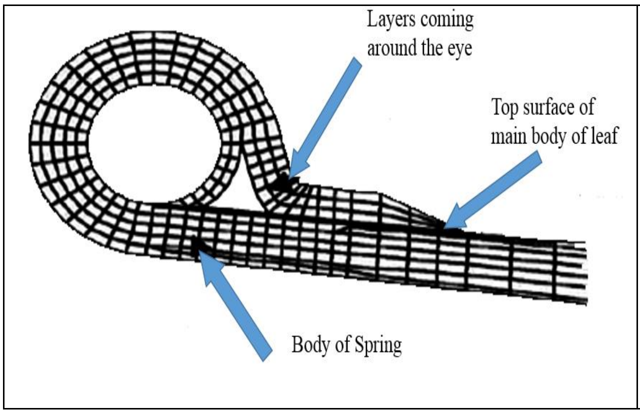

Figure 1: Eye End of the Leaf Spring
(Adhesive type)

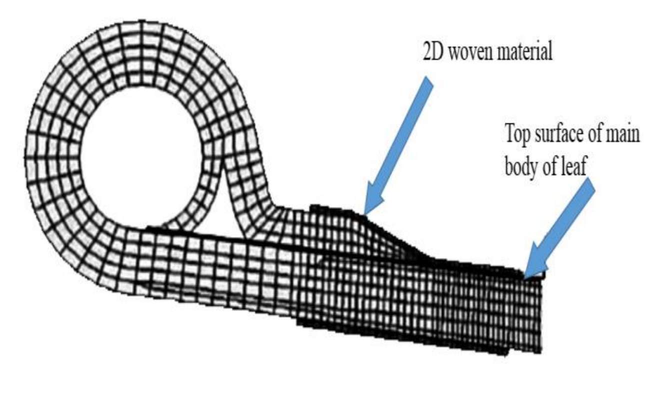

Figure 2: Eye End of the Leaf Spring
(Bonding + wrapping)

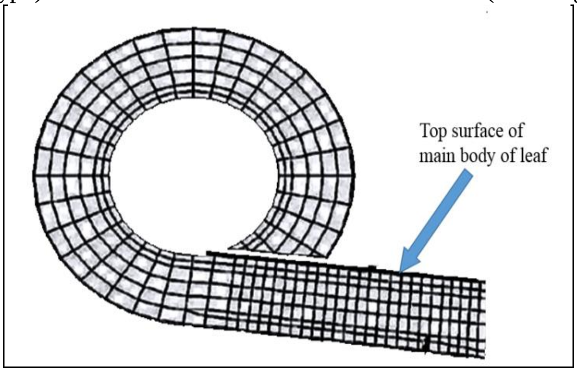

Figure 3: Eye End of the Leaf Spring (Separate)

The leaf spring is generally installed between the frame and the axle. It mainly serves as a buffer and shock absorption function. Since the effect of the force link, complicated force of the rolling eyes, its manufacturing process requirements are high. There are three methods for the creating rolling eyes of composite leaf springs, as shown in figure 6, in which the extension fiber of the rolling eyes and the leaf spring body are bonded together called adhesive type. Whereas as in figure 7, wrapped the bonded roll eye extension fiber and the spring body with a fiber, hence called the bonding and wrapping type, and figure 8 is the open type or separate type in which the end of the rolling eye and the spring body are separated. Considering the difficulty and reliability of processing, the leaf spring used in this study is formed by extending and crimping the main spring itself. This can avoid the two forms shown in figure 6 and figure 7.

4.3 Constraints of the Finite Element Model

Since the leaf spring assembly is clamped on the axle with U-shaped bolts in the middle, the constraints of this model are imposed on the nodes in the middle of the leaf spring assembly at the bottom of the leaf spring assembly, restricting the degrees of freedom of the nodes in all directions. As shown at point C in figure 9, for the double-leaf leaf spring, a vertical displacement constraint is applied at the middle node O of the top leaf spring. The magnitude of the displacement is the gap between the double leaf springs (35 mm). The spring will deform and bond together under the action of displacement load. Thereby simulating leaf spring assembly in the assembled further pre-stressed U-shape at the middle. A concentrated

load is applied to the two ends of the spring A and B to simulate the force of the vehicle load on the leaf spring assembly, mainly by rigid coupling treatment on the inner surface of the end eye. Then the concentrated load is applied to the centre node of the end eye. The specific method is to first create a node at the centre of the end eye. All nodes on the surface and the central node are rigidly coupled as shown in figure 10.

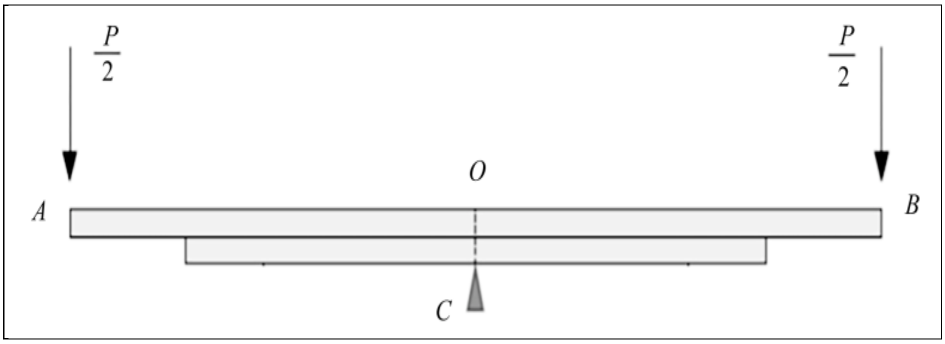

Figure 4: Schematic Diagram of Landing and Restraint of the Leaf Spring Assembly

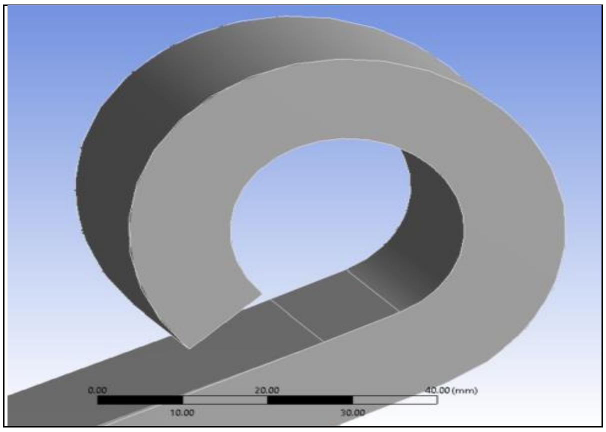

Figure 5: Schematic Diagram of the Rigid Coupling of the Eye

IV. FINITE ELEMENT ANALYSIS

As mentioned earlier, the geometric model of the leaf spring is established in the Solid Works 2017 software and then imported into the ANSYS finite element software. Loads and constraints are applied to the finite element model of the leaf spring, and the equivalent stress diagram and displacement response diagram of the leaf spring are calculated. The material properties of four different fiber-reinforced composite materials are respectively assigned. The calculation results and analysis of a composite leaf spring are as follows.

5.1 Finite element analysis of leaf spring

Since the leaf spring is subjected to the force exerted by the central bolt and the U-shaped bolt during the installation process, the first load step in the finite element analysis is to apply a displacement load to simulate the pretension of the leaf spring. The displacement in the direction is 37.753 mm, and the middle node of the second leaf spring is fully constrained (Fig. 11). Figure 12 shows the stress distribution of the leaf spring after assembly. The maximum stress is in the middle of the leaf spring. The lower surface of the main spring can be seen from the figure. The upper surface is compressed, and the lower surface is tensioned. Therefore, the application of assembly stress is beneficial to the load of the

leaf spring during operation, thereby improving the life of the main spring. The free arc height of the steel plate spring assembly after prestressing is 153.8 mm.

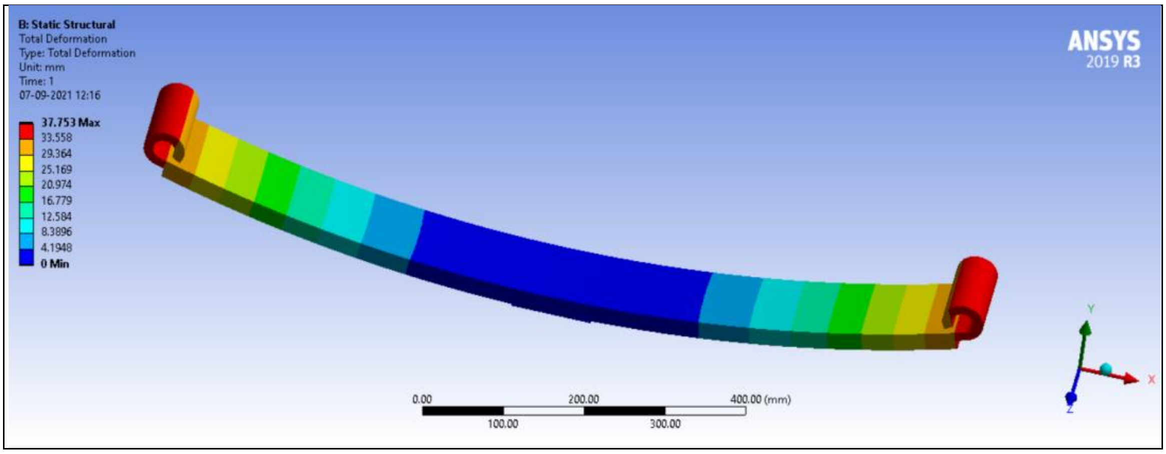

Figure 6: Displacement Diagram

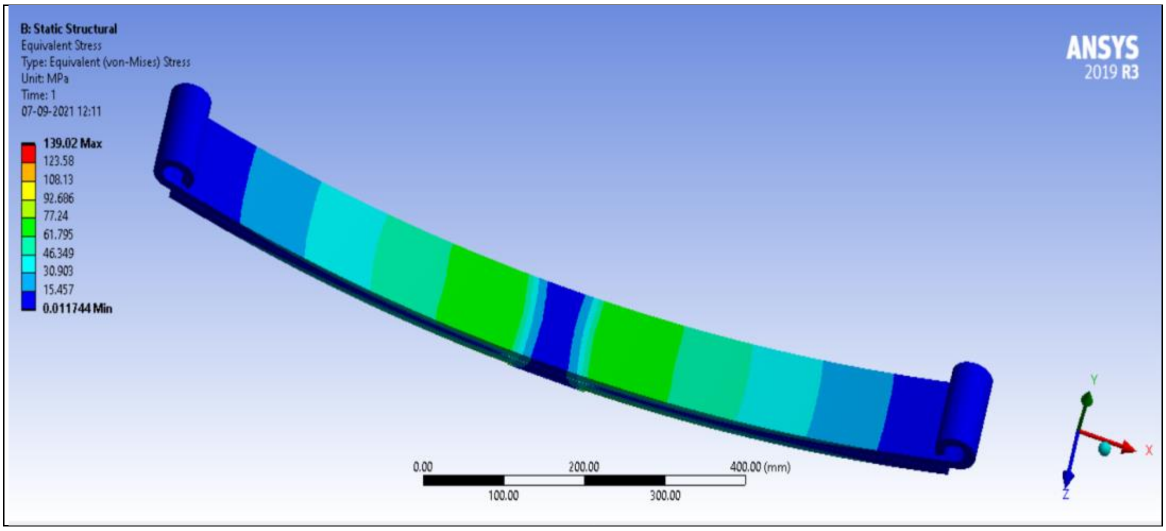

Figure 7: Equivalent Stress Diagram

Different concentrated loads are applied to the eye at both ends of the steel spring, which are 1700 N, 2000 N, 3000 N, and 4000 N. The corresponding four-wheeled vehicle loads are 6800 N, 8000 N, 12000 N, and 16000 N. The equivalent stresses and displacement analysis diagram is shown in Figures from No. 13-20 below.

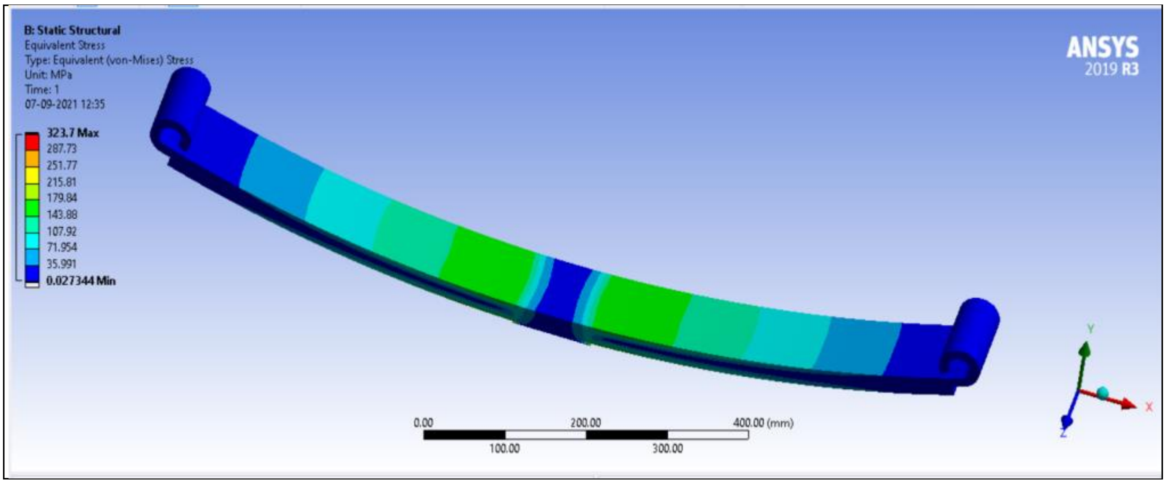

Figure 8: Equivalent Stress at 1700 N

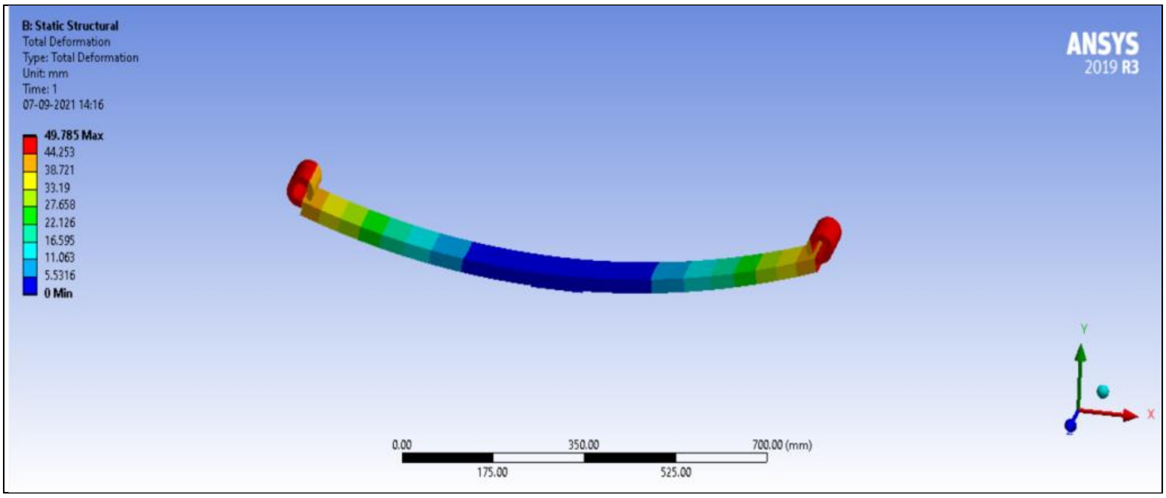

Figure 9: Deformation at 1700 N

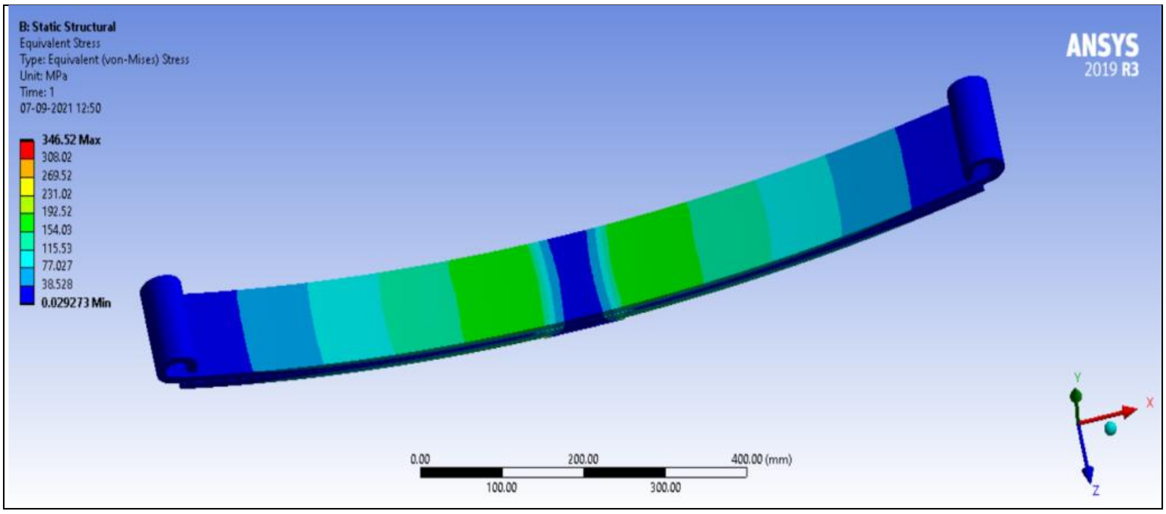

Figure 10: Equivalent Stress at 2000 N

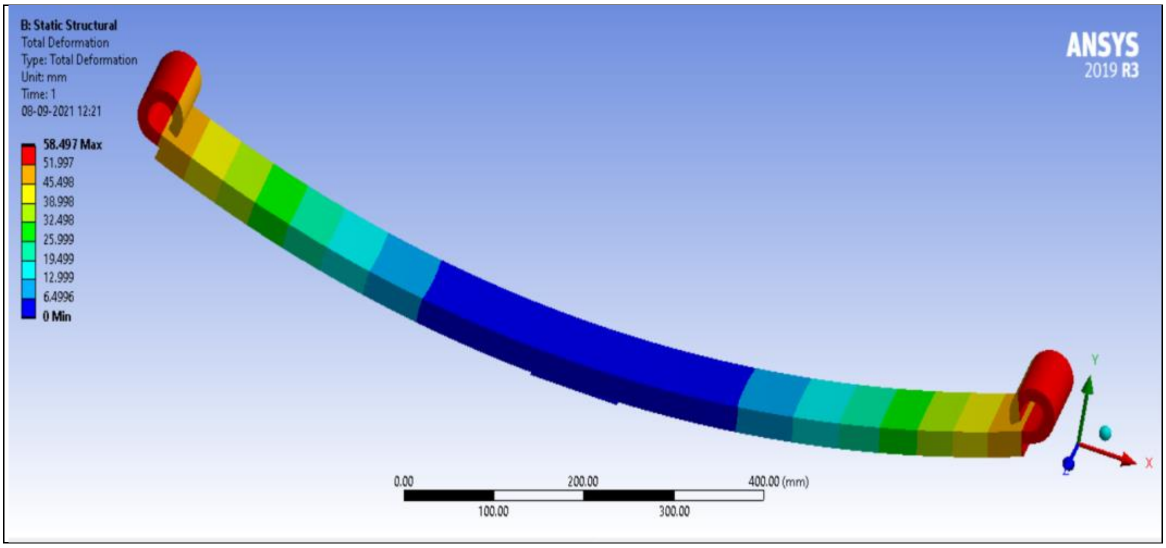

Figure 11: Deformation at 2000 N

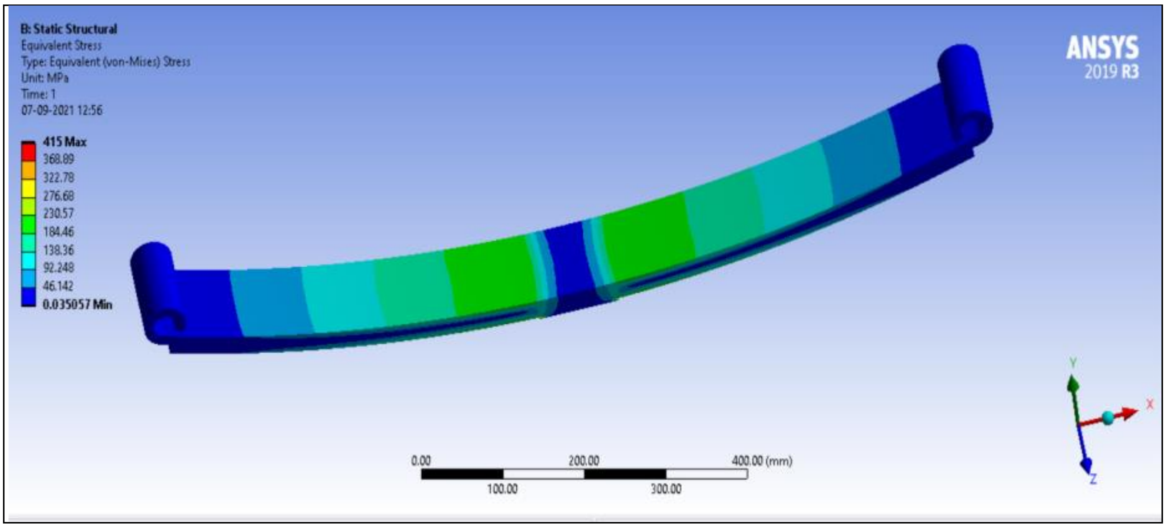

Figure 12: Equivalent Stress at 3000 N

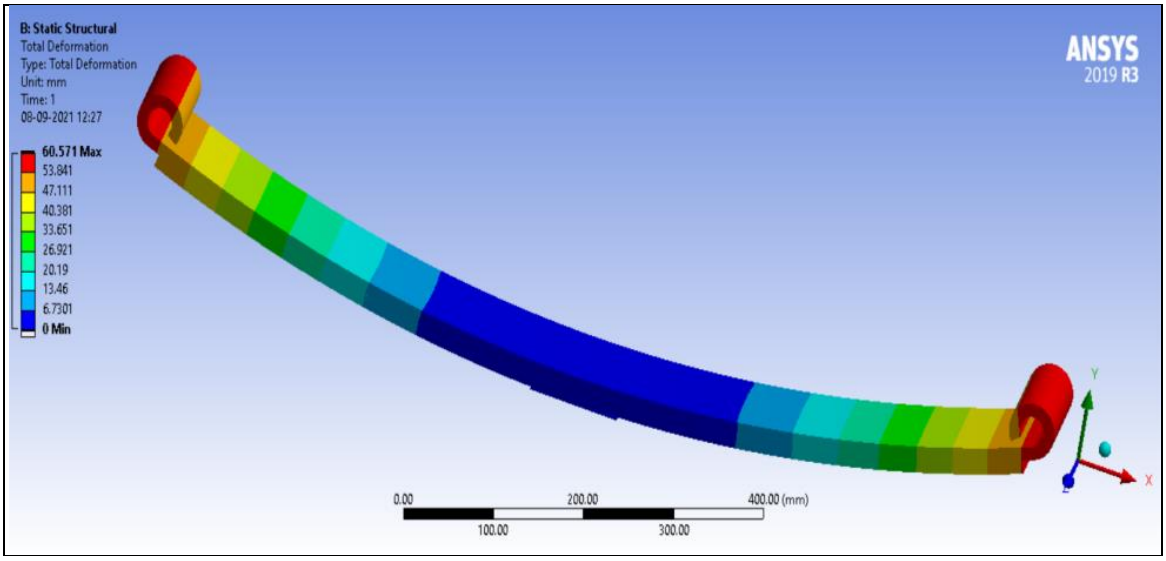

Figure 13: Deformation at 3000 N

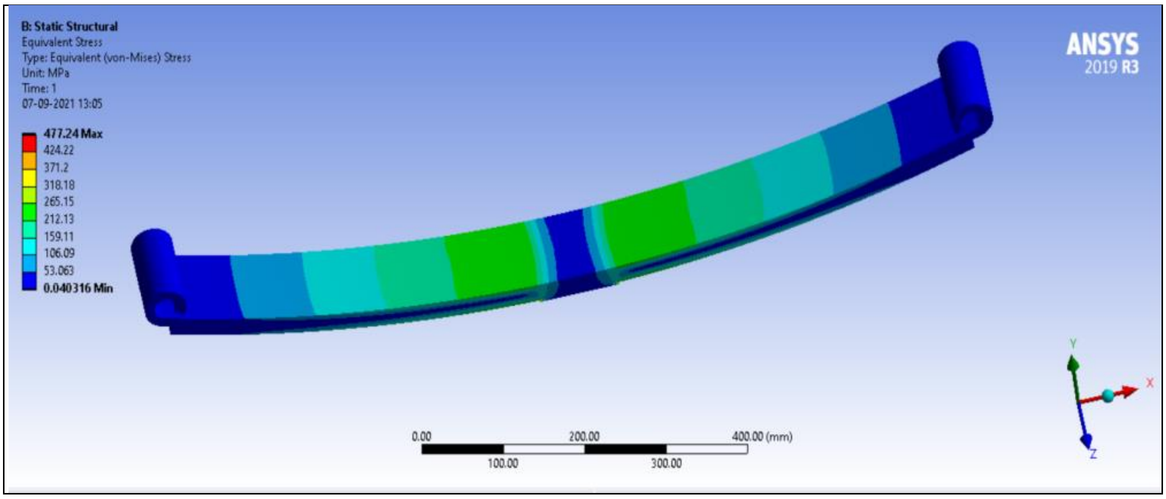

Figure 14: Equivalent Stress at 4000 N

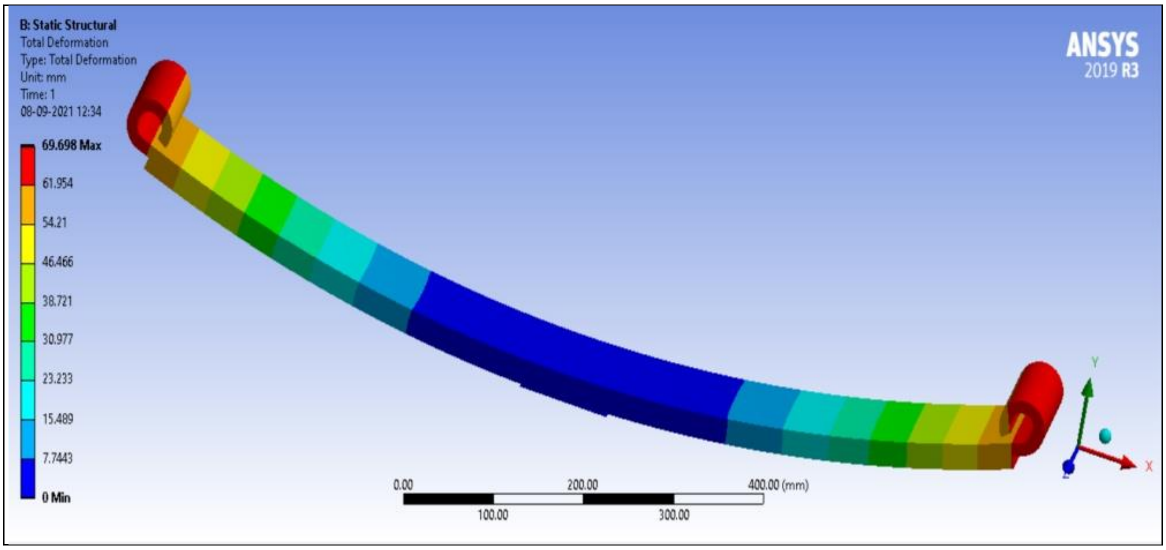

Figure 15: Deformation at 4000 N

The maximum equivalent stress and displacement values under different loads are shown in table 5.

Table 4: Finite Element Analysis Results of Steel Leaf Spring

Load /N	Equivalent Stress /MPa	Displacement /mm
1700	323.7	49.785
2000	346.52	58.497
3000	415	60.571
4000	477.24	69.698

Figure 20 shows the results that the maximum stress of the steel leaf spring assembly is located near the middle of the leaf spring, that is, the U-shaped bolt so the stress in this region is the maximum. The upper part is tensioned, and the lower part is compressed. In addition, the displacements of the eye on both sides are the maximum, and the stress is small. According to the common curvature method, the stiffness of the leaf spring is calculated to be 71.3 N / mm.

$$K = \frac{48\,EI_0}{L^3\delta_1}\ (N/mm) \qquad (1)$$

$$\delta_1 = \frac{1.5}{1.04\,(1+\frac{n}{2n_1})}\ (N/mm) \tag{2}$$

Where: δ1 = is the deformation increase coefficient,

n = is the total number of leaf springs

Seen from the above finite element analysis, leaf spring maximum deformation occurs in the volume of the full eye maximum displacement (17.1 to 69.6) mm.

Therefore, the leaf spring stiffness is fully loaded:

$$K = \frac{F}{f} = \frac{4000}{(69.6-17.1)} = 76.2\ (N/mm) \tag{3}$$

Compared with the theoretical stiffness of the leaf spring, the stiffness obtained by the finite element simulation is too large, which may be because the leaf spring model does not consider the central hole and the form of the lifting lug. However, the error between is only 6 4%. In the acceptable range so it can be considered that the model has been verified.

5.2 Finite Element Analysis Results of Composite Leaf Springs

The properties of four different fiber-reinforced composite materials of the geometric models of leaf springs are given, and then solved in ANS Y S 2019 R3. The results are shown in Table 6. The maximum equivalent stress result, maximum displacement result and weight reduction effect of the leaf spring are shown in figures from Nos. 21-24 given below at full load (4000 N).

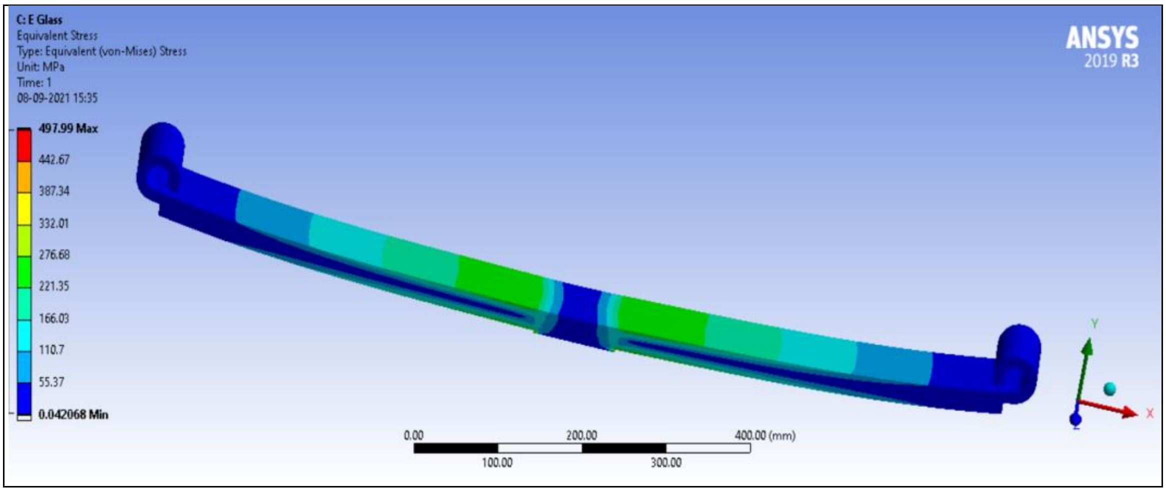

Figure 16: Equivalent Stress of Double Leaf Spring Under Load 4000 N (E-Fiber Glass)

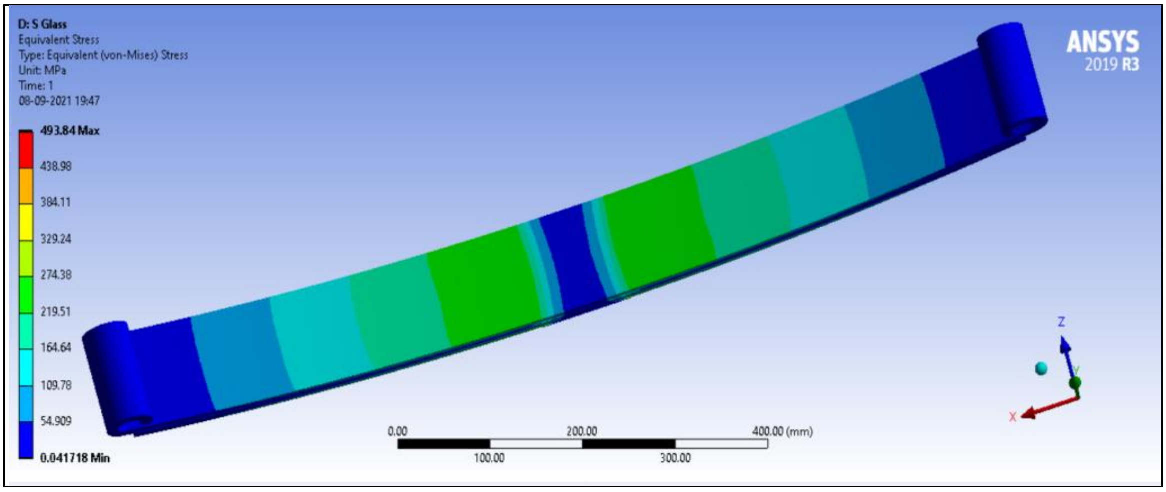

Figure 17: Equivalent Stress of Double Leaf Spring under 4000 N Load (S Glass Fiber)

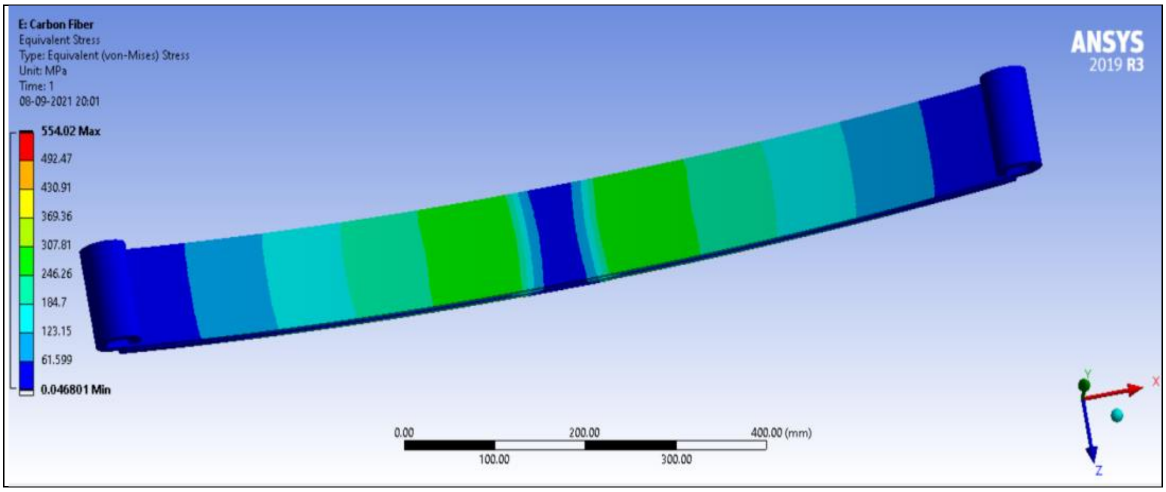

Figure 18: Equivalent Stress of Double Leaf Spring under 4000 N Load (Carbon Fiber)

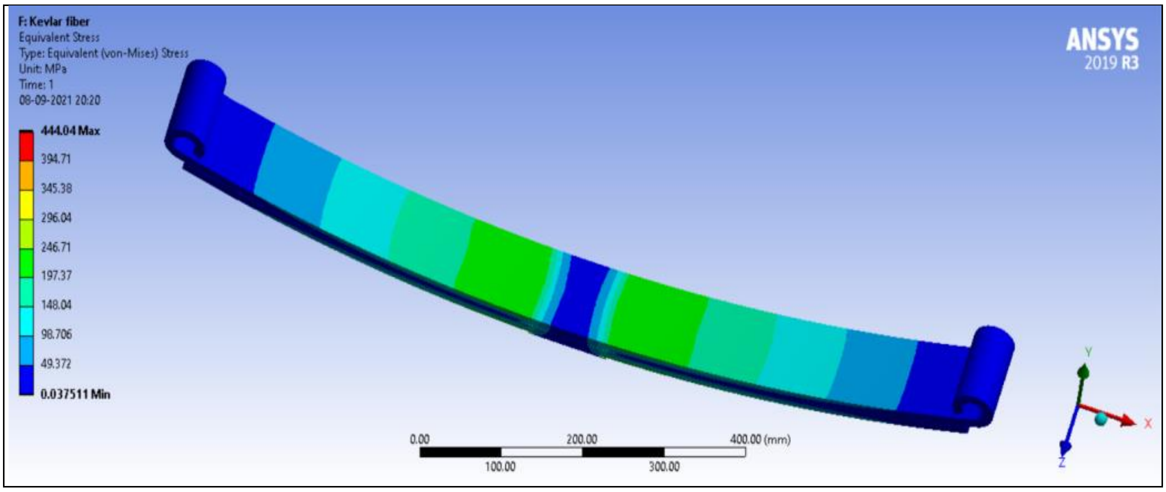

Figure 19: Equivalent Stress of Double Leaf Spring under Load of 4000 N (Kevlar Fiber)

Table 5: Comparison of Results of Different Composite Material Leaf Springs

Material	Equivalent Stress (2000 N) /MPa	Equivalent Stress (4000 N) /MPa	Deformation (2000 N) /mm	Deformation (4000 N) /mm	Weight Loss
E Glass fiber (Two Leaf)	218.6	497.99	119.5	190.8	74.6
S Glass fiber (Two Leaf)	213.4	493.84	113.3	1789	74.6
Carbon fiber (Two Leaf)	388.2	554.02	54.5	78.9	80.4
Kevlar fiber (Two Leaf)	271.3	444.04	74.7	108.9	82.2
E Glass fiber (Single Leaf)	150.5	346.52	41.6	73.2	80
S Glass fiber (Single Leaf)	147.4	342.37	39.1	68.2	80
Carbon fiber (Single Leaf)	118.1	249	13.6	24.1	84.6
Kevlar fiber (Single Leaf)	114.5	282.2	21	36.1	86

From the comparison of the results in Table 6, among the four materials, the equivalent stress of the E glass fiber epoxy composite leaf spring under different loads is smaller, the displacement deformation is the largest, and the full load deflection is much greater than that of the leaf spring. The deflection is close to that of the leaf spring, which meets the design requirements, and its weight is reduced by 80% compared with the steel leaf spring (The weight of the steel leaf spring is 18.5 kg. The weight of the E glass fiber leaf spring is 3.69 kg). In addition, the two forms of carbon fiber epoxy composite leaf spring have better strength, deflection and weight reduction effect, and the Kevlar fiber has the best weight reduction effect. Therefore, it can be seen from the above results that composite materials can replace traditional steel materials and can achieve very significant weight reduction. In addition, it is worth noting that the stress of composite material leaf springs at the joint between the coil eye and the spring body is easy to concentrate, so it is recommended Special attention should be paid to the handling here when designing or manufacturing. Based on the above results, the performance, cost, lightweight effect and molding process of these four reinforced composite materials are comprehensively compared. The E glass fiber epoxy composite leaf spring is the most cost-effective and competitive. The leaf spring is further reduced in weight.

VI. RESULTS AND OPTIMAL DESIGN

6.1 Optimal Design of Composite Leaf Spring Structure

The above-mentioned composite material leaf spring adopts a variable cross-section form of constant width and variable thickness. Next, the optimized design of the cross-sectional form of variable width and thickness will be carried out. According to the theory of concentrated load method, it can be seen that the leaf spring can be regarded as a cantilever beam has one end fixed and one end loaded. When the cross section of the leaf spring is rectangular, the normal stress of the cross section of the beam at any length is:

$$\sigma = \frac{My}{I} = \frac{3P_x}{bh^2} \tag{4}$$

Where: P is the load, x is the length from the fixed support, b is the width, and h is the thickness.

According to equation (4), for the variable width and equal thickness section, when the maximum stress and load of the leaf spring are given, the leaf spring edge can be obtained. Width at any section in the length direction:

$$b = \frac{3P_x}{\sigma h^2} \tag{5}$$

According to the above formula, suppose the stress is 500 MPa and the load is 4000 N. The width of the leaf spring along the length can be obtained by solving. Due to the coil eye at both ends, the width at the end of the leaf spring remains unchanged. The small position can appropriately reduce the cross-sectional width. Finally, at the position of the quarter point of the leaf spring (excluding the midpoint), the cross-section is set to the minimum, and the size of the leaf spring is calculated. The free arc height of the composite leaf spring and the metal leaf spring assembly is the same. Its end thickness is 11 mm, and the root is 22 mm. The outer contour of the spring body transitions in a parabolic form. The equivalent stress and displacement results of the E glass fiber composite leaf spring and the optimized variable width E glass fiber composite leaf spring are shown in Table 7 and Table 8.

Table 6: The Equivalent Stress Comparison of Two Different Variables of Composite Material Leaf Springs (MPa)

Variable / Load	2000 N	4000 N	Weight Loss Effect
Original single piece E glass fiber leaf spring / MPa	**150.5**	**346.52**	**80 %**
Single piece variable width E glass fiber leaf spring / MPa	**187.6**	**404.8**	**85.2 %**

Table 7: Displacement Comparison of Two Different Forms of Composite Material Leaf Springs (MPa)

Variable / Load	2000 N	4000 N
Original single piece E glass fiber leaf spring / mm	**41.6**	**73.2**
Single piece variable width E glass fiber leaf spring / mm	**49.5**	**87.3**

From the above data comparison, the fully-loaded von-mises stress of the optimized single-piece variable-width composite leaf spring is about 58 MPa compared with the original glass fiber leaf spring. The displacement and deflection deformation of the leaf spring has also become about 14 mm, but it is still being designed. Within the allowable range, in the automotive field, when the component structure meets the relevant requirements, designers begin to pay attention to the weight issue, because the weight reduction can not only greatly reduce the cost, but also improve the car's driving smoothness, handling stability, and reduce fuel consumption. After calculation, the optimized design of the single-piece variable-width E glass fiber composite leaf spring reduces the weight of the original single-piece E glass fiber composite leaf spring by about 5.2%. In summary, although the optimized E glass fiber composite leaf spring has only a slight increase in full load stress and deflection, it can further reduce weight, so it is quite necessary to optimize the structure of the composite leaf spring.

6.2 Safety Factor

The safety factor is a coefficient used to reflect the degree of structural safety, that is, the ratio of the load that the engineering structure can bear in theory to the actual load. It is also used as an important reference for structural design. In this study, it is defined as the ratio of the yield stress to the working stress. The working stress is the maximum stress value when the leaf spring is loaded. Table 9 shows the calculated value of the safety factor of three different leaf springs.

Table 8: Safety Factor Comparison

Variable / Load	Safety Factor 2000 N	Safety Factor 4000 N
Original single piece E glass fiber leaf spring	**4.48**	**1.95**
Single piece variable width E glass fiber leaf spring	**3.6**	**1.67**
Double Leaf Spring (Steel)	**1.59**	**1.15**

By comparing the data in Table 9, the optimized design of the single-piece variable-width E glass fiber composite leaf spring has a smaller safety factor than the original single-piece E glass fiber composite leaf spring, but it is higher than that of the steel plate spring, indicating that the composite material Leaf springs are safer than steel springs. It is feasible to replace steel plate springs with composite materials.

6.3 Vibration Frequency

If the leaf spring generates self-excited vibration during use, it will not only affect the comfort of passengers, but also accelerate the fatigue damage of the leaf spring. Therefore, the natural frequency of the leaf spring must be considered to avoid resonance conditions related to the road frequency. The maximum fluctuation frequency is 12 Hz. If the natural frequency of the leaf spring is greater than this value, no resonance will occur. The fundamental frequencies of the three leaf springs calculated in the finite element are shown in Figure 25.

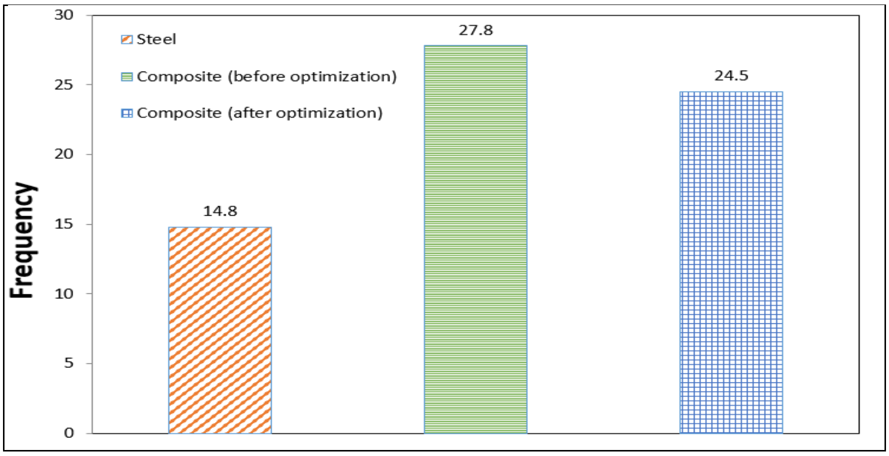

Figure 25: Comparison of Natural Frequencies of Different Types of Leaf Springs

From the results in the figure, the natural frequency of the steel plate spring assembly is 14.8 Hz, and its frequency is closer to that of the road surface. It is relatively easy to resonate. This will affect the service life of the leaf spring, driving stability and comfort. A certain influence, the first-order frequency of the composite leaf spring is relatively high, although the optimized single-chip variable width E fiberglass leaf spring is slightly lower than the original single-chip E fiberglass leaf spring, but it is much greater than the road frequency. This shows that the possibility of composite leaf springs resonating with roads is greatly reduced compared to leaf springs, which can extend their service life.

6.4 Strain Energy

Materials account for about 60% ~ 70% of the cost of the vehicle. Different materials have a great impact on the weight and performance of the vehicle. Therefore, the strain energy of the material is an important factor that needs to be considered in the lightweight design of the component. The main function of the spring is to absorb and store energy

through deformation, and finally release the energy. Therefore, a leaf spring with good energy storage capacity can improve the performance of the car and reduce the damage to it on uneven roads. The relationship can be expressed as:

$$U = \frac{\sigma^2}{\rho E} \tag{6}$$

Where: σ is the stress, ρ is the density, and E is the modulus of elasticity.

The strain energy of the three types of leaf springs under full load is shown in Figure 26.

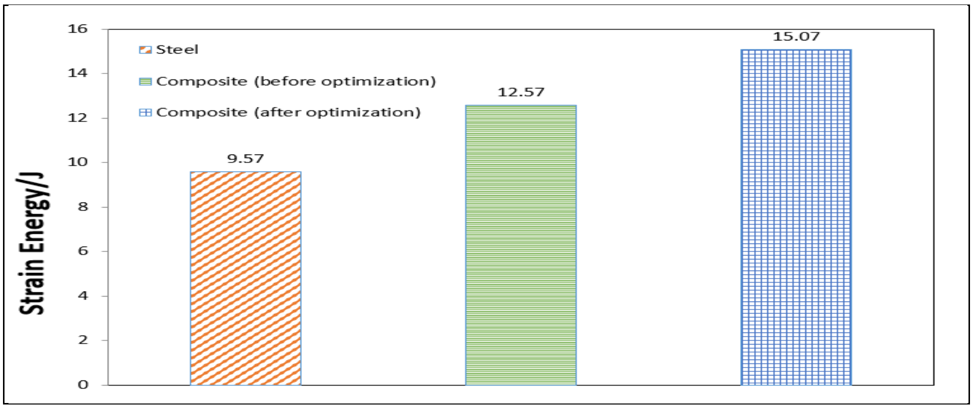

Figure 26: Comparison of Strain Energy

It can be seen from the data in the figure that the strain energy of the two forms of composite material leaf springs is higher than that of steel plate springs, which indicates that the deformation energy storage capacity of composite material leaf springs is stronger than that of steel plate springs, and the optimized single-piece variable width E The glass fiber composite leaf spring is higher than the original single-piece E glass fiber composite leaf spring, which proves that structural optimization can further improve the ability of the composite leaf spring to store strain energy and improve the performance of the vehicle.

VII. CONCLUSIONS

In this paper, the finite element analysis of a lightweight design for automobile leaf springs is carried out using four different types of composite leaf springs, namely E glass/epoxy, S glass/epoxy, Carbon fiber and Kevlar fiber. In addition, composite leaf springs with two forms of single-leaf and double-leaf springs have been considered to explore the performance of different forms of leaf springs of the same material. Finally, by looking for the best change in the width of the cross-section, the structural design was further carried out to reduce the weight. Based on this, the following conclusions have been drawn:

- Four different fiber-reinforced composite materials were used, and two leaf spring models were established, two-piece leaf springs, which were calculated by ANSＹS 2019 R3. The spring works, and the weight reduction effect is obvious.
- To further reduce weight, the structure of the single-piece E glass fiber composite leaf spring was optimized, and its cross-sectional width was changed. The finite element analysis results showed that the optimized single-piece variable-width E glass fiber composite leaf spring has the same performance. Under the conditions that meet the

requirements, its weight is further reduced by 5.2% since the weight reduction of the original single-piece E glass fiber composite leaf spring.

- The safety factor, vibration frequency and strain energy of the three leaf springs of steel plate springs, single-sheet equal-width E glass fiber composite leaf springs and single-sheet variable width E glass fiber composite leaf springs are analyzed. The results show that E glass fiber composite the material leaf spring is safer than the steel plate spring, and the lightweight effect is obvious. Among them, the safety factor and frequency of the single-piece variable-width E glass fiber composite leaf spring are not much different from the original single-piece equal-width E glass fiber composite leaf spring. It's strain energy is higher.

Based on the above analysis results, the optimized variable width E glass fiber composite leaf spring has the best overall performance, and the lightweight effect is obvious. Therefore, in the lightweight design process of the leaf spring, in addition to the use of new composite materials, it can also be used. Within the range allowed by the cost and molding process, the structure of the composite leaf spring should be further optimized to achieve the maximum economic benefit.

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